"On the Recovery of Iron from Overstrain." By JAMES MUIR, B.Sc., Trinity College, Cambridge (1851 Exhibition Science Research Scholar, Glasgow University). Communicated by Professor EWING, F.R.S. Received January 25,—Read February 9, 1899.

(Abstract.)

It has long been known that iron which has been overstrained in tension—that is to say, strained beyond the yield-point, so that it suffers a permanent stretch—possesses very different elastic properties from the same iron in its primitive condition. The material is said to be "hardened" by stretching,* since the ultimate effect of such treatment is to raise the elastic limit, and reduce the ductility of the material.

More recently attention has been called to the fact that, primarily, the result of tensile overstrain is to make iron assume a semi-plastic state; so that the elastic limit instead of being raised by stretching is first of all lowered, it may be, to zero.† This plasticity may be shown by applying a comparatively small load to a bar of iron or steel which has just been overstrained by the application and removal of a large stretching load. When the small load is put on, the bar will be found to elongate further than it would had the material been in its primitive state; and a slight continued elongation—a "creeping"—may occur after the small load has been applied. If this load be withdrawn a quite appreciable permanent, or semi-permanent, set will be fouud to have been produced; a set which diminishes slightly and, if small, may vanish provided time be allowed for backward creeping to take effect. It may also be shown that if the reapplied load be increased the elongation produced will increase in a greater proportion. Thus if a stress-strain curve be obtained from a recently overstrained bar of iron or steel, it will show even for small loads a marked falling away from the straight line which would indicate obedience to Hooke's law.

It is the recovery from this semi-plastic state induced by overstrain to a condition of perfect or nearly perfect elasticity, with raised elastic limit, that is referred to in the title of the paper of which this is an abstract. Such recovery is known to be effected by mere lapse of time,‡ and the object of the experiments described in the paper and

* Ewing, "On certain Effects of Stress," 'Roy. Soc. Proc.,' No. 205, 1880.

† Bauschinger, 'Civilingenieur,' 1881, or 'Mittheilungen aus dem Mech. Tech. Laboratorium in München.' An Account of Bauschinger's work is given in Unwin's book on 'Testing of Materials of Construction.' Ewing, "On Measurements of Small Strains in the Testing of Materials and Structures," 'Roy. Soc. Proc.,' vol. 58, April, 1895.

‡ Bauschinger, 'Dingler's Journal,' vol. 224, p. 5; or 'Mittheilungen aus dem Mech. Tech. Laboratorium in München.' Ewing, both papers already cited.

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summarised here, is to show the effect of moderate temperature, of mechanical vibration, and of magnetic agitation on this slow return to the elastic state; and further to illustrate this recovery by means of compression tests. One section of the paper deals with the phenomenon of hysteresis in the relation of extension to stress which is exhibited in a marked degree by iron in the overstrained state. Incidentally attention is called to subsidiary points of interest.

The experiments were carried out in the Engineering Laboratory of Cambridge University, and were the outcome of suggestions by Professor Ewing. It was on his suggestion that the effect of moderate temperature on recovery from overstrain was tried, and the result of that trial led to much of the work incorporated in the paper.

The straining and testing were done by means of the laboratory 50-ton testing machine, the specimens employed for the most part being taken from steel rods one inch in diameter, of a quality which may be described as semi-mild. The small strains of extension were measured by Professor Ewing's extensometer.*

After referring to the apparatus and the material employed, and describing the method of experimenting, there are first given in the paper examples of the slow recovery of elasticity with lapse of time. These examples are illustrated by stress-strain curves obtained, at succeeding intervals of time, from extensometer readings similar to those tabulated by Professor Ewing in his paper, referred to above, "On Measurements of Small Strains in the Testing of Materials and Structures." Recovery is shown to be at first comparatively rapid; but latterly very slow progress is made, and weeks or months may be required before an approximately perfect restoration of elasticity is effected. When this is brought about, the specimen may be subjected to a stress a few tons per square inch higher than that at which the virgin material yielded, before a yield-point is passed and the material once more brought into a semi-plastic state. If sufficient time be allowed to elapse after passing this second yield-point, an elastic state will again be assumed, and a third yield-point may be obtained about as far above the second yield-point as the second was above the first. In this manner four or five yield-points may be obtained with the same specimen before fracture occurs. A specimen broken in this manner shows greater ultimate strength, but less ultimate elongation than would have been obtained had fracture been brought about in the usual fashion, that is, without allowing intermediate recoveries of elasticity to take place.

Reference might also be made to Lord Kelvin's discovery of the effect of a Sunday's rest on wires which had been subjected to torsional vibrations throughout the preceding week.

* For description see paper already cited, "On Measurements of Small Strains, &c.," 'Roy. Soc. Proc.,' vol. 58, April, 1895.

The question of recovery of elasticity under stress is next considered in the paper, and it is shown that the process of recovery proceeds at practically the same rate whether the material is kept stressed or is allowed to rest free from load. A slight difference, however, is shown in the two cases, as restoration of elasticity takes place about the position of continued stress.

After this, the phenomenon of hysteresis in the relation of extension to stress is considered, and a closed cycle is shown, having features analogous to those exhibited by a magnetic hysteresis cycle.*

The effect of moderate temperature on recovery from overstrain is next treated of, and it is shown that a slight increase in temperature hastens the restoration of elasticity to a remarkable extent. Three or four minutes at 100° C. proved to be more efficient than a fortnight's rest at the normal atmospheric temperature. The effect of various temperatures below 100° C. is then investigated, and so moderate a temperature as 50° C. is shown to have a large influence in hastening recovery from overstrain. The manner in which recovery proceeds with time when the specimen is kept at a constant temperature is shown in the paper by means of curves. These curves show that at first—that is, before elasticity is fairly well restored—the amount of recovery, measured by the diminution in the elongation produced by a maximum load, is proportional to the square root of the time. For example, the effect produced by, say, four minutes at 80° C. was approximately double of that produced by one minute at the same temperature.

By subjecting an overstrained specimen to temperatures above 100° C., no effect (other than the recovery from the temporary effect of overstrain) was found to be produced until a red heat was almost attained. When the specimen had been subjected to an annealing temperature, of course the whole effect of overstrain was removed, and the material assumed its virgin state.†

After the effect of temperature is discussed, that of mechanical vibration is next recorded in the paper; and it is shown that by striking a recently overstrained specimen with a hammer, so as to make it ring, the material of the specimen is made less elastic. That is, the effect of mechanical vibration is opposite to that of increase of temperature; recovery of elasticity is not hastened, but the material becomes more semi-plastic after mechanical vibration than it was before.

The influence of magnetic agitation is next described. A recently overstrained specimen was subjected to magnetic reversals by means of a coil giving a field strength of 140 C.G.S. units at its centre, but no

* Ewing, "Experimental Researches in Magnetism," 'Phil. Trans.,' 1885, or book on 'Magnetic Induction in Iron and other Metals.'

† See paper by Unwin, "On the Yield-point of Iron and Steel, and the Effect of repeated Straining and Annealing," 'Roy. Soc. Proc.,' vol. 57, 1895.

change whatever was detected in the elastic condition of the material; the process of recovery seemed to be neither accelerated nor retarded.

For the compression experiments described in the paper, an instrument, specially designed by Professor Ewing, was employed to measure the small compressional strains. By the aid of this instrument, the semi-plasticity of recently overstrained iron was readily observed, and the effect of moderate temperature in restoring elasticity was demonstrated by means of compression tests. The lowering of the compression yield-point which accompanies the raising of the tension one (due to tensile overstrain) was also clearly shown. This lowering, however, was not found to be such as to keep the total range of elasticity for the material constant; that is, the lowering of the compression yield-point was not found to be equal to the raising of the tension one.

In conclusion, the characteristics of overstrained iron are considered as illustrating Maxwell's views on the "Constitution of Bodies," as set forth by him in the 'Encyclopædia Britannica.'

"A Soil Bacillus of the Type of De Bary's *B. megatherium*." By W. C. Sturgis, M.A., Ph.D. Communicated by Professor H. Marshall Ward, F.R.S. Received January 27,—Read February 9, 1899.

(Abstract.)

The organism which forms the subject of these investigations was isolated from clayey and gravelly soil, at a depth of about an inch below the surface. It is a straight, or slightly curved bacillus of rather large size, measuring $3{\cdot}4$—$7{\cdot}7\mu \times 1{\cdot}2$—$1{\cdot}5\mu$, and occurs either as isolated rods or in the form of long chains. Its peculiar interest lies in the fact of its marked predilection for acid media, and its behaviour in the presence of carbohydrates. It also offers peculiar advantages for the study, by direct observation in hanging drops, of the formation and germination of the spores, the formation of gelatinous sheaths, the co-existence of motile and non-motile stages, and the rejuvenescence of so-called involution forms, the former process especially being very rapid under suitable conditions.

The organism forms on solid, acid media, such as saccharose-gelatine, large, domed, translucent drops, consisting of chains of rods provided with thick, firm, and gelatinous sheaths. The latter character is exhibited only in media containing carbohydrates, especially cane sugar; in media devoid of carbohydrates the colonies are slimy rather than gelatinous, and consist of almost naked rods and chains. Moreover, even in the presence of sugar, the formation of an investing sheath is largely dependent upon the age of the culture, the vigour of the